15

Virginia Soelberg

STATEMENT TO ENVIRONMENTAL PROTECTION COMMISSION

RULE FOR APPLYING MANURE ON FROZEN OR SNOW-COVERED GROUND

The Commission is considering a draft rule to regulate the application of manure on frozen or snow-covered ground. The Sierra Club Iowa Chapter has the following comments on the rule.

It is extremely important to regulate such application because manure applied to frozen or snow-covered ground will not be absorbed into the ground or by any crops on the field. Nor can manure be injected into frozen or snow-covered ground. If not absorbed, the manure will run off into surface waters.

We are pleased that this rule will apply to all confinement operations that are required to have a manure management plan or a nutrient management plan and to all open feedlots that are required to have a nutrient management plan. We are concerned, however, that a recent change in the draft exempts operations that have received a notice of violation. The rule was changed to apply only to operations that have had enforcement actions, i.e., administrative orders. This change is problematic because the Iowa DNR is very reluctant to issue administrative orders. So the operator could have had a problem and should be subject to the rule, but because of DNR reluctance to issue an administrative order, the operator would not be regulated under the rule.

Also, the rule states that application is prohibited on frozen ground with slopes of 2 percent or greater unless soil conservation practices are in place and the P-Index rating is less than 2. The rule does not say what conservation practices are contemplated. If there are soil conservation practices that will stop the runoff of manure from frozen ground those practices should be specified in the rule. In addition, the P-Index is essentially a measure of the phosphorous content and erodibility of unfrozen soil. So using the P-Index in this rule gives a false sense of security and should not be used as a factor.

The rule also allows application of manure on frozen ground depending on the slope of the ground. We have not seen any justification for using these particular slope criteria. And there are other criteria that should be considered in addition to slope that may justify prohibition of application of manure on frozen ground even if the slope meets the specifications of the rule. *

The real problem with this rule is that it complicates an issue that should be addressed simply and directly. The rule should just prohibit application of manure on frozen or snow-covered ground. There is no reason that an animal feeding operation should have to apply manure to frozen or snow-covered ground.

DES MOINES WATER WORKS
Board of Water Works Trustees

Des Moines Water Works
Water You Can Trust for Life

2201 George Flagg Parkway | Des Moines, Iowa 50321-1190 | (515) 283-8700 | www.dmww.com

COMMENT DOCUMENT
Proposed Rule for Manure on Frozen and Snow-Covered Ground
December 9, 2008

My name is Chris Jones and I'm an employee of the Des Moines Water Works. I'm here to today to comment on the Proposed Manure on Frozen and Snow Covered Ground Rule.

The utility believes the proposed rule is well-researched and well-written. The author is knowledgeable and familiar with practices in Iowa, has done a good job of investigating environmentally-sound practices in surrounding states and translating that information into a common-sense approach for Iowa. It is clear, based on ammonia data from this past spring, that manure applied in this fashion is a threat to Iowa's streams and drinking water sources.

The utility wishes to emphasize that this proposed rule is only a starting point when approaching water quality problems associated with manure. Some might say that restrictions on the application of manure to frozen ground and snow will do little or nothing to solve Iowa's water quality problems. So they say, why have any rule at all? My response is that our problems are such that no one thing is going to solve them. Some say producers need the option to apply to frozen ground because they cannot be expected to cope with every weather condition and mechanical failure. I guess what we're saying is that downstream users must accept the onus of their inability to cope.

This rule must be considered one tool in what must surely be a kit of many tools that will help us begin to deal with the externalities of animal agriculture. Externalities are costs that are external to a system or market and that are usually socialized. An example for agriculture might be restoring a stream killed off by a manure spill or the cost to remove nitrate from drinking water. I am distributing this paper published in 2005 by Erin Tegtmeier and Mike Duffy of the Leopold Center at Iowa State that quantifies the externalities of agriculture. Using the authors' estimates, which they claim to be conservative, I calculate the external costs of agriculture in Iowa to be somewhere between $430 million and $1.3 billion. Should society have some reasonable tools to try cope with these costs? I think we should, and the proposed rule could be one.

In the funnels that are the Raccoon and Des Moines River Watersheds upstream from our surface water intakes, there exist 3.5 million hogs; 170,000 sows; 540,000 nursery pigs; 320,000 cattle; 18 million chickens and 2.5 million turkeys. How we cope with the untreated waste from these animals, a volume comparable to that produced by 15-20 million human beings, is an unresolved problem. If agriculture's expectation is that we continue to socialize the external costs that exude from this industry, then is it not a reasonable expectation that society try to manage these costs? The utility believes the proposed rule is one small step in that direction.

Finally, we urge agriculture not to be satisfied with the status quo, or even small, incremental improvements in environmental performance. Until larger leaps are achieved, tools such as the proposed rule will be necessary. The Des Moines Water Works supports the proposed rule as written.

Christopher S. Jones

Christopher S. Jones, Ph.D.

Chris Jones

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY
1473-5903/04/01 0001-20 $20 00/0

Vol. 2, No. 1, 2004

External Costs of Agricultural Production in the United States

Erin M. Tegtmeier and Michael D. Duffy

Department of Economics, Iowa State University, Ames, Iowa, USA

Agricultural production affects environmental and human health. Many consequences are borne involuntarily rather than chosen because no formal market trading takes place for ecosystem functions or health attributes. These impacts, or externalities, may be quantified indirectly by assigning dollar values through a process called valuation, which informs agricultural production and policy decisions. This study estimates external costs of agricultural production in the United States in the areas of natural resources, wildlife and ecosystem biodiversity and human health. Valuation studies are reviewed and revised to compile aggregate figures. External costs are estimated at $5.7 to $16.9 billion (£3.3 to £9.7 billion) annually. Impacts due to crop production are figured to be $4969 to $16,151 million per year. Livestock production contributes $714 to $739 million to external costs. Using 168.8 million hectares of cropland in the United States, external cost per cropland hectare is calculated at $29.44 to $95.68 (£16.87 to £54.82). Further research is needed to refine these estimates and include categories not covered in this study. The societal burden of these costs calls for a restructuring of agricultural policy that shifts production towards methods that lessen external impacts.

Keywords: adverse effects, agriculture, externalities, valuation

Introduction

All agricultural practices impact the environment. Industrial agriculture is increasingly being recognised for its negative consequences on the environment, public health and rural communities. Soil loss and erosion reduce crop yields and impair natural and manmade water systems (Atwood, 1994; Clark *et al.*, 1985; Crosson, 1986; Evans, 1996; Holmes, 1988; Pimentel *et al.*, 1995). Runoff of agricultural chemicals from farm fields contaminates groundwater and disrupts aquatic ecosystems (Conway & Pretty, 1991; Pimentel *et al.*, 1992; Pretty *et al.*, 2003; USDA, 2000d; Waibel & Fleischer, 1998). Monocropping and feedlot livestock production threaten diversity and may increase foodborne pathogens and antibiotic resistance in humans, as well as pest resistance to chemical controls (Altieri, 1995; Iowa State University and The University of Iowa Study Group, 2002; National Research Council, 1989). The health of rural communities is affected negatively by declining community involvement and increased division of social classes (Bollman & Bryden, 1997; Flora *et al.*, 2002).

The costs of impacts are external to agricultural systems and markets for products. They are borne by society at large. Assessing the monetary costs of such impacts aids in fully identifying their consequences. Cost estimates can inform and guide policymakers, researchers, consumers and agricultural producers and may encourage a closer look at the impacts of industrial agriculture.

According to Western neoclassical economics, well-defined property rights ensure that an owner benefits exclusively from use of property and wholly incurs the costs of use. However, in many circumstances, costs are borne by those who are not decision-makers. Impacts of agriculture involve costs to individuals and communities who are not making decisions about production methods. These consequences indicate when property rights are not well defined and they represent market failures, which lead to economic inefficiencies. In an unregulated situation, a polluter will weigh the private costs and benefits of an action, producing too much pollution with too little cleanup or producing too much product at too low a price (Miranowski & Carlson, 1993; Samuelson & Nordhaus, 1995).

Because these effects occur outside the marketplace, they are called externalities. 'Negative' externalities occur when costs are imposed; 'positive' externalities occur when others gain benefits without charge. To identify forces resulting in externalities and actions that may mitigate their effects, economists distinguish types of externalities. They can be broadly classified by the nature of their consumption (public *vs* private) and by their effects on resource allocation (pecuniary *vs* technological).

An externality is 'consumed' by those affected by it. Many externalities have the characteristic of a public good (or bad) where consumption by one individual does not reduce the good's availability to others nor the utility of consumption received by others (Baumol & Oates, 1988). For example, polluted air or scenic views are experienced in this way. They are public and undepletable and are not exchanged in the marketplace where each consumer can be charged for use. A private externality, however, is depletable. If an individual dumps trash onto another's property, this affects only the victim (Baumol & Oates, 1988). Externalities that affect public goods are of greater policy interest because there are fewer 'defensive activities' available to victims.

Externalities also are differentiated by whether the competitive marketplace can adjust to their effects. In the context of agriculture, soil erosion is a technological externality, whereas the decline of rural communities as a consequence of the character and structure of large, industrial farms is considered pecuniary. Research has described declines in purchases from local businesses, increases in crime and civil court cases and decreased property values (Flora *et al.*, 2002). These effects, although undesirable, are not results of market failure in the neoclassical sense. They are, rather, results of the market responding to changes in supply and demand.

Economists and policymakers rely on valuation, or the process of assigning economic value, to apply the concept of externalities. A monetary metric provides a base for comparisons to aid in policy decisions. Externalities, however, often are highly complex and difficult to delineate. Even though assumptions are necessary, economists continue to refine techniques and view valuation as a way of revealing problems with the status quo.

A key assumption underlying valuation is that economic value of an object or service is derived through a function that contributes to human well-being and can be measured by 'establishing the link between that function and some service flow valued by people' (Freeman, 1998: 305). Measurement is based on the concepts of willingness to pay (WTP) for the improvement of an object or service or willingness to accept compensation (WTAC) for its deterioration (Farber *et al.*, 2002; Hanley *et al.*, 1997). Valuation approaches generally fall into two categories: direct survey methods and indirect methods (Hanley *et al.*, 1997; Zilberman & Marra, 1993). Survey techniques seek to measure individual preferences for improvement in a situation or loss of wellbeing associated with a condition. Indirect valuation methods observe behaviour in related markets and use such data as proxies.

In all valuation efforts, sufficient and reliable data are a concern. People who are surveyed often do not have well-defined preferences to which they can assign value or they simply may not be familiar with the services provided by an environmental resource (Hanley *et al.*, 1997). Also, value for many resources is composed of both use values and non-use values that may be particularly difficult to delineate (Hanley *et al.*, 1997). Non-use values include existence value (the value of knowing a thing merely exists, regardless of intent to use) and option value (the value of preserving a resource for possible future use).

We continue to learn about the intricacies of ecosystems on a societal level, but critical data that would strengthen current indirect valuation projects often are not available. Also, environmental externalities, especially those associated with agriculture, frequently have broad spatial and temporal effects, adding to the complexity of valuation efforts.

Study Framework

This study assembles available valuation data to arrive at an aggregate, national figure for particular external costs of agricultural production in the United States. We focus on technological externalities with public goods characteristics. A literature review revealed data on such externalities in three broad damage categories:

- natural resources (comprised of water, soil and air subcategories);
- wildlife and ecosystem biodiversity; and
- human health (comprised of pathogen and pesticide subcategories).

A study on the total external costs of agriculture in the United Kingdom (Pretty *et al.*, 2000) guided our work. Pretty *et al.* compiled data from various datasets and studies to estimate costs, categorised by damages to natural capital and human health.

They calculated costs of £208 per hectare of arable land and permanent pasture. This figure is higher than the cost per cropland hectare for the United States reported here. The difference, in part, may be due to the inclusion of costs of the BSE (bovine spongiform encephalopathy or 'mad cow') crisis and the difference in agricultural land area. Also, the UK study included costs to public agencies for monitoring and administering environmental and public health programmes associated with agriculture.

We collected programme costs in the form of agency budgets, but decided not to incorporate them into our total cost figure. This is not meant to diminish the research and conclusions of Pretty *et al.* But, considering the available data for direct costs, we feel that using programme costs as proxies could be viewed as double counting. And, as Pretty *et al.* acknowledge, such activities may be necessary for any type of agricultural production. However, programme costs would likely decrease if agriculture were more environmentally benign.

Other studies on agricultural cost accounting in the UK include Adger and Whitby (1991, 1993) and Hartridge and Pearce (2001). Estimates can be found for other European countries as well: Denmark (Schou, 1996), France (Bonnieux *et al.*, 1998; le Goffe, 2000; Piot-Lepetit *et al.*, 1997) and Italy (Tiezzi, 1999). A discussion on integrating agricultural externalities for a number of countries in the European Union can be found in Brouwer (1999).

For the United States, work has been done by Faeth and Repetto (1991), Hrubovcak *et al.* (2000), Smith (1992) and Steiner *et al.* (1995). The study by Steiner *et al.* is the most comparable to our research in that it compiles available data on national estimates of agricultural externalities. Our analysis relies on some of the same sources, indicating how the lack of current, available data limits investigation. Steiner *et al.* (1995: 210) also acknowledge that external costs ideally should be calculated on a 'location-specific basis – which currently is impossible because of a lack of information'. We subsequently have found a dearth of local or regional data to qualify the national figures.

Steiner *et al.* focused on externalities caused by pesticides, fertilisers and soil erosion and included regulatory programme costs. As reported in 1987–1990 dollars, these costs total \$1.3–3.6 billion, \$12–33 million and \$5.8–20.3 billion, respectively. In effect, we update their study and add information on the treatment of surface water for microbial pathogens, human health costs caused by foodborne pathogens and greenhouse gas emissions. We also attempt to identify, within the scope of the damage categories, a total cost figure attributable to agriculture and a cost figure per cropland hectare.

Methods

Previous studies that assign values to specific impacts of agriculture in the United States form the basis of our analysis. Cost estimates are revised and updated to reflect changes in conditions and the Consumer Price Index. Final figures are in 2002 dollars.

Two points in the methodology call for further clarification. We used the Consumer Price Index as opposed to one of the other indices available because we felt that the impact of externalities would be more directly felt by consumers than producers. A second point concerns the changes in technology or production practices that may have occurred since the original estimates were made. In our calculations of damages due to soil erosion, we deflate some of the estimates by a multiplier to address the subsequent decrease in soil erosion. However, this methodology does not fully account for the changes. There really is not a clean way to make such adjustments. This issue points to the need for more updated estimates.

Cost estimates are classified according to production type (crop or livestock) and area-based external cost figures for crop production are also calculated. Agricultural land use areas reported by the United States Department of Agriculture (USDA, 2000b) are used. Of 184.1 million hectares of cropland in the United States, approximately 15.3 million are idled each year. The remaining 168.8 million hectares is used for area-based calculations. The external cost of crop production within each damage category is divided by 168.8 million hectares to arrive at cost per hectare figures. Area-based figures are not calculated for those external costs associated with livestock production, considering that production practices and the land areas they affect vary greatly and depend on the animal being raised.

Table 1 presents our resulting national tally. Table 2 summarises programme budgets of agencies associated with agricultural activities.

Table 1 Selected annual external costs of US agricultural production (2002, million $)

	Damage categories	Costs	C/L[a]
1	*Damage to water resources*		
1a	Treatment of surface water for microbial pathogens	118.6	L
1b	Facility infrastructure needs for nitrate treatment	188.9	C
1c	Facility infrastructure needs for pesticide treatment	111.9	C
	Category 1 Subtotal	**419.4**	
2	*Damage to soil resources*		
2a	Cost to water industry	277–831.1	C
2b	Cost to replace lost capacity of reservoirs	241.8–6044.5	C
2c	Water conveyance costs	268–790	C
2d	Flood damages	190–548.8	C
2e	Damages to recreational activities	540.1–3183.7	C
2f	Cost to navigation: shipping damages, dredging	304–338.6	C
2g	Instream impacts: commercial fisheries, preservation values	224 2–1218 3	C
2h	Off-stream impacts: industrial users, steam power plants	197.6–439.7	C
	Category 2 Subtotal	**2242.7–13,394.7**	
3	*Damage to air resources*		
3a	Cost of greenhouse gas emissions from cropland	283.8	C
3b	Cost of greenhouse gas emissions from livestock production	166 7	L
	Category 3 Subtotal	**450.5**	
4	*Damage to wildlife and ecosystem biodiversity*		
4a	Honey bee and pollination losses from pesticide use	409.8	C
4b	Loss of beneficial predators by pesticide applications	666.8	C
4c	Fish kills due to pesticides	21.9–51.1	C
4d	Fish kills due to manure spills	11.9	L
4e	Bird kills due to pesticides	34.5	C
	Category 4 Subtotal	**1144.9–1174.1**	
5	*Damage to human health – pathogens*		
5a	Cost of illnesses caused by common foodborne pathogens	375.7	L
5b	Cost to industry to comply with HACCP rule	40.7–65.8	L
	Category 5 Subtotal	**416.4–441.5**	
6	*Damage to human health – pesticides*		
6a	Pesticide poisonings and related illnesses	1009.0	C
	Category 6 Subtotal	**1009.0**	
	TOTALS:	5682.9–16,889.2	
		(£3256.3–9677.5 million)	

[a]C/L, refers to production type that is main cause of impact: crop or livestock

Table 2 Associated costs – agency budgets (million $)[a]

	Damage categories	Costs	C/L[b]
1	*Damage to water resources*		
1d	USEPA FY2003 budget requests for Nonpoint Source Programme and state grants (USEPA, 1997b, 2001a, 2002d)	153.2	C&L
4	*Damage to wildlife and ecosystem biodiversity*		
4f	USEPA FY2003 budget for Reduce Public and Ecosystem Risk from Pesticides goal (USEPA, 2002d)	21.9	C
4g	USDA FY2003 budget for Natural Resources Conservation Service (USDA, 2002b)	1260.0	C&L
4h	USDA FY2003 budget for Farm Service Agency Conservation Programmes (USDA, 2002b)	1968.0	C&L
	Category 4 Subtotal	**3249.9**	
5	*Damage to human health – pathogens*		
5c	USDA Food Safety and Inspection Service FY2003 budget (USDA, 2002b)	27.2	L
5d	FDA Food Safety Initiative FY2002 estimated budget (FDA, 2002)	8.4	L
5e	USDA ARS FY1999 budget for food safety, pathogen preharvest research (USDA, 2002a)	21.2	C&L
5f	USDA APHIS FY2003 budget for Plant & Animal Health Monitoring (USDA, 2002b)	143.0	C&L
5g	USDA AMS FY2003 budget for Microbiological Data Programme (USDA, 2002b)	1.5	C
	Category 5 Subtotal	**201.3**	
6	*Damage to human health – pesticides*		
6b	EPA Safe Food Programme FY2003 budget request (USEPA, 2002a, 2002d)	86.7	C
6c	USEPA FY2003 budget for Reduce Public and Ecosystem Risk from Pesticides goal (USEPA, 2002d)	27.7	C
6d	USDA AMS FY2003 budget for Pesticide Data Programme (USDA, 2002b)	15.0	C
	Category 6 Subtotal	**129.4**	
	TOTAL:	3733.8	
		(£2139.5 million)	

[a]Contact authors for calculation information on programme costs
[b]C/L, refers to production type that is main cause of impact: crop, livestock or both

Following the tables, each damage category is further described with calculation details.

Results

(1) Damage to water resources

Impacts on water resources are gauged by the costs of treatment necessary to control major pollutants associated with agricultural production (microbial pathogens, nitrate and pesticides).

(1a) Treatment for microbial pathogens

Microorganisms in livestock waste can cause several diseases and human health problems. *Cryptosporidium* and *Giardia* are waterborne, disease-causing parasites (USDA, 2000e). They are found in beef herds and *Cryptosporidium* may be prevalent among dairy operations (Juranek, 1995; USDA, 1994, 2000d). *Cryptosporidium* oocysts have been found in 67–97% of surface water sampled in the United States according to the Centers for Disease Control and Prevention (CDC, 1996)

The Interim Enhanced Surface Water Treatment Rule is one of the EPA's latest rulings on microbial protection addressing *Cryptosporidium* and continuing requirements for *Giardia* and viruses. According to the EPA's Office of Water, the total annualised national cost for implementing this rule is $307 million (USEPA, 1998a). There are three potential sources of both *Giardia* and *Cryptosporidium*: wildlife, domestic livestock and humans (Pell, 1997). From this, we assume that livestock causes one-third, or approximately 35%, of the damages associated with these pathogens. Applying 35% to $307 million, $107.5 million of the national cost to meet the ruling may be due to livestock production. Updated from 1998 to 2002 dollars, the cost is $118.6 million.

(1b) Treatment for nitrate

Nitrate, a compound of nitrogen, can leach into groundwater sources or be carried by soil particles into surface waters via runoff. Agricultural sources of nitrate include fertilisers, livestock waste and mineralisation of crop residues. Agricultural regions have been shown to be highly vulnerable to nitrate contamination of surface and groundwater (USDA, 2000d). Nitrate impairs aquatic ecosystems and is a human health concern. It can be converted to nitrite in the gastrointestinal tract and may prevent the proper transport of oxygen in the bloodstream, causing methemoglobinemia, or 'blue-baby syndrome' in infants (USDA, 2000d).

Human activities have doubled the amount of nitrogen in our ecosystems since the 1970s through atmospheric deposition of nitrogen compounds (USEPA, 2002b). Fossil fuel combustion is the primary source of nitrogen oxides (NO_x). Transportation-related sources (engines in vehicles) account for 53% of these emissions, totaling 10–11 million tonnes of NO_x, and large, stationary utility and industrial boilers account for 45% (USEPA, 2002b). Emissions of ammonia (NH_3) from livestock and fertilised croplands contribute to atmospheric deposition of ammonium (NH_4) (Vitousek *et al.*, 1997, as cited in Lawrence *et al.*, 1999). Because ammonium is highly water-soluble, it tends to be deposited closer to emission sources than nitrogen oxides.

The EPA estimated, in 1995 dollars, a total investment of $200 million was needed immediately for water treatment facilities to meet federal nitrate standards. Also, an estimated $3.3 billion is needed over 20 years to replace and maintain water system infrastructure to meet surface water, coliform and nitrate standards (USEPA, 1997a). Considering the additional cost for infrastructure maintenance, we use $200 million as an annual cost. Pretty *et al.* estimated that 80% of nitrate pollution is due to agriculture. We apply this same percentage to $200 million. In 2002 dollars, the facilities cost is $188.9 million per year.

For comparison, Crutchfield *et al.* (1997) employed WTP survey methods to estimate the value placed on reducing nitrates in drinking water for households in four regions in the United States. Estimates were $314–351 million per year.

Water treatment costs for nitrate are associated mostly with background levels of inorganic nitrogen from fertilisers. Catastrophic manure spills occur intermittently and are not considered here. Many farmers, but not all who should, appropriately credit nitrogen applied to cropland via manure.

(1c) Treatment for pesticides

Pesticides from agriculture enter surface and groundwater systems through runoff and leachate and pose risks to aquatic and human health. Approximately 447 million kilograms of active ingredients from pesticides are currently used in crop production in the United States (Gianessi & Marcelli, 2000) and a number of studies have detected pesticides in water supplies (USDA, 2000d).

The EPA estimated a total need of $400 million, in 1995 dollars, for treatment facilities to meet Safe Drinking Water Act (SDWA) regulations for pesticides and other chemicals (USEPA, 1997a). Approximately 30% of the chemicals listed are pesticides (USEPA, 1998b). Also, agriculture's share of national, conventional pesticide usage is 79%(USEPA, 1999a). So, the $400 million figure is revised using multipliers of 30% and 79%. Updated to 2002 dollars, the annual cost is $111.9 million. This figure does not account for many unregulated pesticides.

Category 1 summary

Total damage to water resources due to agricultural production, according to available research, is calculated to be $419.4 million per year. Crop or livestock production is associated with these costs as follows:

- Livestock – treatment for microbial pathogens ($118.6 million); and
- Crop – infrastructure needs for treatment of nitrate and pesticides ($300.8 million).

Using the above cost totals and 168 8 million hectares of cropland, water resources are impacted by cropland at a level of \$1.78 per hectare annually.

This is not a complete review of all impacts on water by agricultural production. Of note, the multifaceted impacts of agricultural chemicals and sedimentation on aquatic ecosystems are not included here. The next subsection on soil resources addresses effects of sedimentation on water treatment, storage and conveyance systems. Valuation also is included for fish kills due to pesticides in Subsection 4. However, these do not fully address structural disturbances to habitats and the food chain of aquatic environments.

(2) Damage to soil resources

Agriculture practices result in soil erosion through tillage, cultivation and land left bare after harvest. After such disturbances, wind and water carry soil particles off the land. In 1997, average annual soil erosion due to water from cropland and land in the Conservation Reserve Program (CRP) was 969 million tonnes, with approximately 958 million tonnes coming off cropland. Erosion due to wind in that same year was 762 million tonnes (USDA, 2000c). Conservation efforts since 1982 have reduced soil erosion by 38% on cropland and CRP land combined (USDA, 2001b), with the composition of the combined land use changing as cropland has been enrolled in the CRP. Still, agriculture remains the single largest contributor to soil erosion. To date, external costs of waterborne erosion have been studied and quantified more than those of windborne erosion. Thus, the costs that follow reflect damages due to waterborne erosion only. Because soil erosion greatly affects the condition and use of surface waters, the following costs support the need for integrated land and water policies.

Erosion reduces soil fertility, organic matter and water-holding capacity and negatively affects productivity. Environmental externalities may result with increases of fertiliser and pesticide use to counteract these effects. On-farm costs of lost productivity due to soil erosion are not included here, assuming the majority of these costs are borne by the producer. Although this is not entirely true, it is beyond the scope of this study to identify on-site effects that have off-site impacts. Some estimates of annual on-farm costs due to soil loss include \$500–600 million (Crosson, 1986), \$500 million to \$1 2 billion (Colacicco *et al*, 1989) and \$27 billion (Pimentel *et al*., 1995)

(2a) Cost to water industry

Sediment causes turbidity in water supplies and transports toxic materials, including fertiliser and pesticide residues that are bound to clay and silt particles. According to Holmes (1988), sediment contributes 88% of total nitrogen and 86% of total phosphorus to the nation's waterways.

Annual costs of supplying water are based on Holmes' method, using a range of treatment costs multiplied by national surface water withdrawals. Updated to 2002 dollars, Holmes' treatment costs are \$26.38–78.22 per million litres. Similarly, the EPA's Office of Water (2001c) claims that the cost to treat and deliver drinking water is approximately \$527.8 per million litres, 15% of which goes to treatment. According to these figures, treatment costs \$79.17 per million litres.

In 1995, water withdrawn for public supply was estimated at 152.174 billion litres per day, of which 63% (approximately 95.87 billion litres per day) was from surface water sources (USGS, 1998).

Holmes (1988) estimated that cropland contributes 30% of total suspended solids. Therefore, costs attributed to agriculture are calculated using 30% of the estimate of 95 87 billion litres per day at a cost of \$26 38–79.17 per million litres. Our numbers, \$277–831 1 million, are likely to be conservative because treatment of groundwater sources and erosion from pastureland are not considered. However, there may be some overlap between these costs and those to meet nitrate water standards as discussed previously.

(2b) Lost capacity of reservoirs

Reservoir capacity lost to sedimentation poses a complex problem. Many existing reservoirs are irreplaceable because of unique site characteristics. Dredging is almost prohibitively expensive at a minimum cost of \$2.50 per cubic metre. Additionally, there are few disposal sites for dredged material. Alternative energy sources may partially alleviate the need for reservoirs for energy production, but, in terms of water storage, the problem remains (Morris & Fan, 1998).

Although building new reservoirs may not be the realistic solution, this impact is calculated in terms of construction costs to provide some valuation of the problem Crowder's model (1987) for assessing the cost of reservoir sedimentation is updated.

Total national water storage capacity is 627.6 billion cubic metres (Graf, 1993; Morris & Fan, 1998) Crowder (1987) reported that 0.22% of the nation's water storage capacity is lost annually. Atwood (1994, as cited in USDA, 1995) examined survey records of reservoirs and lakes and found an average storage loss of 5% from sediment depletion.

Construction costs for new capacity from 1963 to 1981 were $243.40–567.70 per thousand cubic metres (Crowder, 1987). Updating the median from 1981 to 2002 dollars yields $802.60 per thousand cubic metres.

Total costs are calculated using 0.2–5% loss of total national capacity (627.6 billion cubic metres) at the $802.60 per thousand cubic metres replacement value According to Crowder's analysis, 24% of sediment is from cropland Reflecting this percentage, final total costs are $241.8–6044.5 million

(2c) Cost to water conveyance systems

Roadside ditches and irrigation canals become clogged and require sediment removal and maintenance to prevent local flooding A cost range of $268–790 million is calculated by updating Ribaudo's (1989) figures for these categories and allotting 50% for the contribution of sediment from cropland (Clark *et al.*, 1985).

Subcategories 2d to 2h

These estimates are based primarily on the work of Clark *et al* (1985) who calculated total erosion effects and applied a multiplier for the percentage due to cropland appropriate to each category However, erosion from cropland has decreased by 38% since this work (USDA, 2001b). To reflect this improvement, the cropland erosion for each category is multiplied by 62% and updated to 2002 dollars.

(2d) Flood damages

Sediment contributes heavily to floods and flood damages by increasing water volumes and heights and settling on property once floodwaters have abated. Figuring the percentage of flood damages that are due to sediment, as well as the percentage of sediment that is due to agricultural practices, is highly speculative, as indicated by the range of estimates.

The estimate by Clark *et al* of flood damages due to cropland erosion, but not including loss of life, is revised by the method discussed above to yield a range of $184.5–548.8 million. Ribaudo (1989) reported a cost range of $653–1546 million in 1986 dollars for annual damages due to soil erosion Using 32% due to cropland, as per Clark *et al.* (1985) and updating to 2002 dollars, the revised range is $343–812 million, but this does not account for decreased erosion rates since the late 1980s.

The Federal Emergency Management Agency (FEMA) reports dollars and lives lost for billion-dollar weather disasters from 1980 to 1997 (FEMA, 2002). Average annual damages are estimated at $6.4 billion in 2002 dollars and 30 lives lost. Numerous studies have arrived at different estimates for the value of a life. An EPA document (1999b) reviews 26 studies and calculates a mean value for avoiding one statistical death to be $5.9 million. The annual cost of floods increases to $6.6 billion when using this valuation for each of the 30 lives lost. Applying percentages of flood damages due to sedimentation (9–22%) and sedimentation due to cropland (32%) as per Clark *et al.* (1985), $190–465 million of this $6.6 billion could be attributable to agriculture.

This last estimate calculated from FEMA data falls within the revised range of Clark *et al.* High and low range estimates are eliminated as potential outliers. Also, the high end of the valuation based on Ribaudo (1989) may be dropped, considering the revision does not account for the subsequent decrease in cropland erosion. So, the range of $190–548.8 million is used in the national tally

(2e) Cost to recreational activities

As sediment builds up in lakes and rivers, surface water recreation, including fishing, decreases. Freeman (1982) determined the costs of water pollution that affect recreation. Clark *et al.* used these cost figures and applied a proportion due to sediment as calculated by Vaughan and Russell (1982) Not included were the costs of accidental deaths and injuries caused by increased turbidity The range revised to 2002 dollars is $540.1–3183.7 million.

(2f) Cost to navigation

Sediment from erosion collects in navigational channels causing groundings and delays, reliance on smaller vessels and lighter loads, and damage to engines due to sand, pollution and algae

To assess value in this category, Clark *et al.* (1985) included only commercial shipping damages from inland groundings ($20–100 million) and costs for dredging by the United States Army Corps of Engineers (USACE), which we update. Accidents and fuel or cargo spills also cause injuries and deaths and damage to public health and the environment; however, these have not been assessed here. According to the Navigation Data Center (USACE, 2003), the FY2002 cost for dredging navigational channels by the Army Corps and its contractors was $922.9 million.

Commercial shipping damages, according to Clark *et al.*, are revised and added to an estimate of national dredging costs. Taking 32% of the result to account for sedimentation from cropland (Clark *et al.*, 1985), the final costs to navigation due to agricultural activities are approximately $304–338.6 million.

(2g) Other in-stream costs: Commercial fisheries and preservation values

Clark *et al.* uses Freeman's (1982) estimates of benefits to commercial fisheries and preservation values that could be gained by controlling water pollution from all sources. Preservation values are non-user values, and, in this case, cleaner water provides non-users with aesthetic and ecological benefits and options for future use. As revised, these annual figures are $224.2–1218.3 million.

Sediment, with its associated contaminants and algal blooms, negatively impacts waterfront property values. A study of lakeside properties in Ohio (Bejranonda *et al.*, 1999) figured benefits to annual rental rates of $23.22–115.90 per ac-ft ($1.88–9.40 per 100 cubic metres) were accrued by reducing the rate of sediment inflow. However, impacts of sediment on property values are not included in the tally because these values cannot be applied nationally and no other sources were found.

(2h) Other off-stream costs: Municipal and industrial users

Municipal and industrial users, including steam power plants, experience increased operational costs associated with dissolved minerals and salts remaining in water received from water treatment suppliers. To avoid scale and algae build-up in water and boiling systems, water needs to be demineralised and treated. Again using revised calculations of Clark *et al.*, these costs are estimated at $197.6–439.7 million.

Category 2 summary

According to this research, total damage to soil resources due to agricultural production is calculated to be $2242.7–13394.7 million per year. Although waterborne erosion is considerable on western rangelands, our sources focused on cropland erosion, which is associated with all of these costs.

Using the above cost totals and 168.8 million hectares of cropland, soil resources are impacted by crop production at a level of $13.29–79.35 per hectare annually. The external cost of the eroded soil itself can be calculated by dividing the total damages due to cropland by 958 million tonnes of erosion from cropland each year. These costs range from $2.34–13.98 per ton of eroded soil.

The damage totals for impacts on soil resources are among the highest for categories covered in this study. Perhaps, this is because a great deal of research exists on soil erosion from agriculture, which has been a long-term concern. Also, the direct effects of soil erosion may be simpler to track and analyse than damages to other categories.

(3) Damage to air resources

Agriculture damages air resources through:

- particulate matter released by soil erosion;
- volatilisation of ammonia (NH_3) from urea and manure fertilisers;
- emissions of nitric oxide (NO) and nitrous oxide (N_2O) from fertiliser applications, field burning and soil denitrification;
- hazardous pollutants from manure storage at concentrated animal feeding operations (CAFOs) (Thorne, 2002); and
- emissions of methane (CH_4) from enteric fermentation and eructation (belching) of ruminant livestock and manure storage (Cavigelli *et al.*, 1998; USEPA, 2003)

Some of these releases are greenhouse gases, which interact with the environment and affect human and ecological health. They cause climate change through atmospheric warming, aggravate pulmonary and respiratory functioning, degrade building materials and contribute to the acidification and eutrophication of water resources.

Greenhouse gas emissions from agricultural sources in 2001 totaled 474.9 million tonnes carbon dioxide equivalents, which represents approximately 7% of total greenhouse gas emissions in the United States, including 70% of all nitrous oxide emissions from anthropogenic activities and 25% of total CH_4 emissions (USEPA, 2003). The net impact of agriculture is lessened by the up-take of carbon by agricultural soils, and policy efforts are underway to promote practices that will increase this carbon sequestration. Agricultural soils provided a sink for 15.2 million tonnes carbon dioxide equivalents in 2001 (USEPA, 2003).

Two sources of valuation for greenhouse gases provide a range of estimates. A study by Titus (1992) considers impacts of climate change to the United States, including effects on agricultural production, increases in energy consumption, sea level rise, heat-related deaths and change in forest biomass. The study calculates that a doubling of CO_2 (and equivalents) could cost $37–351 billion per year (1992 dollars). Also, the marginal cost of climate change from burning one gallon of gasoline is calculated at $0.16–0.36, at a 3% discount rate. This translates to $20–50 per tonne carbon dioxide equivalents (2002 dollars).

The Chicago Climate Exchange enables member corporations, municipalities and other institutions to trade greenhouse gas credits in an effort to 'determine the most cost-effective means of reducing overall emissions' (Chicago Climate Exchange, 2004). Members who have reduced emissions receive credits, which can be sold to other members. The final market price for 2003 carbon dioxide equivalents closed at $0.98 per tonne. This is much lower than the range calculated in the Titus study. This is not surprising because the trading price is what companies are willing to pay for emission reductions and does not necessarily reflect health and environmental externalities. Also, participation in the Exchange is strictly voluntary.

However, in the interest of being conservative, we use $0.98 per tonne carbon dioxide equivalents. As discussed, net emissions from agriculture in 2001 were 459.7 million tonnes carbon dioxide equivalents, according to the United States Emissions Inventory (USEPA, 2003). Total damage from agriculture is then calculated at $450.5 million.

EPA emission data suggest that 63% of this cost is from crop production ($283.8 million) and 37% is from livestock sources ($166.7 million), as follows:

- Crop – soil management, burning crop residues and rice cultivation; and
- Livestock – enteric fermentation and manure management.

Using the above cost totals and 168.8 million hectares of cropland, air resources are impacted by cropland at a level of $1.68 per hectare annually.

(4) Damage to wildlife and ecosystem biodiversity

These costs involve impacts to bird, fish and insect populations, which, in turn, influence ecosystem biodiversity. With approximately 447 million kilograms of active ingredients used in agricultural production (Gianessi & Marcelli, 2000), pesticides affect ecosystem balance.

Our primary valuation source is a study on the environmental impacts of pesticides by Pimentel *et al.* (1992). We acknowledge that since this research was done formulations and application methods of some pesticides have changed to reduce toxicity. For example, the use of granular carbofuran has been severely restricted since 1994 (Pesticide Management Education Program, 1991). The EPA estimated in the 1980s that granular carbofuran killed one to two million birds each year. In spite of this, the restrictions continue to be challenged as evidenced by the recent emergency use request of rice growers in Louisiana. The EPA initially approved use of granular carbofuran on 4050 hectares, but this was reduced to 1010 hectares after public comments were received (American Bird Conservancy, 2002; National Coalition Against the Misuse of Pesticides, 2002).

Aside from the effects of pesticide use, we do include one calculation to value fish killed by manure spills. But, other known environmental stressors associated with agriculture are not represented here. These include inorganic fertiliser runoff and its impact on aquatic ecosystems and the suppression of biodiversity by monocultural practices. Again, impacts on natural ecosystems are difficult to track and analyse and valuation studies are few. Our coverage of this category is far from comprehensive.

(4a) Honeybee and pollination losses

Pollinators, especially honeybees, are fundamental to ecosystem and agricultural stability. Various studies have attempted to value the agricultural services of pollinators. Southwick and Southwick (1992) estimated $1.6–5.7 billion in total annual benefit to agricultural consumers in the United States from honeybee pollination. Morse and Calderone (2000) claim the annual value of honeybee pollination to be $14.6 billion, in terms of increased yields and product quality.

For our purposes, the more conservative economic impact of pesticide use on honeybees as calculated by Pimentel *et al.* (1992) is used. Their estimate of $319.6 million is figured in terms of colony losses, reduced honey production and crop pollination and the cost of bee rentals. Assuming original reporting in 1992 dollars, the annual figure is $409.8 million in 2002 dollars.

(4b) Loss of beneficial predators

Most pesticide applications not only affect the primary crop pest, but also natural enemies of the pest. As the population of beneficial insects drops, outbreaks of secondary pests occur, which in turn lead farmers to apply more pesticide. The cost of these additional applications and crop losses associated with secondary pests is $666.8 million, updating the figure as per Pimentel *et al* (1992).

Although these costs could be considered on-site, they are included because the invertebrate loss due to broad-spectrum pesticides affects not only crop production, but also the ecosystem as a whole. In addition, pesticides may harm microorganisms. The number and activity of microorganisms in the soil are measures of soil and ecosystem health, as they break down organic matter and cycle nutrients.

(4c) Fish kills due to pesticides

Pesticides contaminate aquatic environments, poisoning fish and damaging their food sources and habitat. It is difficult to calculate losses in severe fish kill events and low-level poisonings are often not detected. Pimentel *et al* (1992) use EPA data to estimate 6–14 million fish deaths per year due to pesticides and values of freshwater fish from the American Fisheries Society (1982), reflecting commercial hatchery production costs of various fish species. We calculate the average of these values, omitting sturgeon and paddlefish over 38 centimetres long, at $1.67 per fish in 1980 dollars, or $3.65 in 2002 dollars. These numbers yield a damage range of $21.9–51.1 million.

(4d) Fish kills due to manure spills

Manure spills, leaks and dumping by animal feeding operations into surface waters also cause damage to aquatic environments and can be partially valued by the number of fish killed in documented events. A report by the Clean Water Network (2000) records information on feedlot spills and associated fish kills in 10 states from 1995 to 1998. Most of the data were collected from state agency databases and reports. More than 13 million fish were killed in over 200 documented manure pollution events. This does not reflect the effects of smaller spills and cumulative impacts and, of course, is not a national count. However, because a high number of animal feeding operations are located in the states included in this report, these numbers are used as a rough proxy for a national estimate. Thirteen million is divided by four years and multiplied by the value of $3.65 per fish given earlier. The estimated annual cost is conservatively set at $11.9 million.

(4e) Bird kills due to pesticides

Birds exposed to pesticides may be poisoned directly or may ingest pesticide residues with prey and seeds. Pesticides affect the life cycle and reproductive ability of birds and their habitats. Toxicity is difficult to quantify, however, considering avian risk assessments customarily test only one to three bird species; the total number of bird species globally is estimated at 10,000, and over 800 species occur in the United States and Canada (Mineau *et al.*, 2001).

Pimentel *et al.* (1992) figure approximately 672 million birds are directly exposed to pesticides on cropland and that 10% of these birds die. The study provides values for a bird's life ranging from $0.40 to $216 to $800. These figures reflect, respectively, cost per bird for bird watching, hunting costs per bird felled and the cost of rearing and releasing a bird to the wild. The higher figures may be considered inappropriate because they are associated with species not as directly affected by agricultural pesticides. By updating the lowest, most conservative valuation to $0.51 per bird death, the cost of bird kills due to pesticides is $34.5 million. This total does not address life cycle and reproductive damages due to poisonings.

Category 4 summary

Total annual damage to wildlife and ecosystem biodiversity due to agricultural production, according to this research, is calculated to be $1144.9–1174.1 million. Pesticide use for crop production is associated with all of the costs, except for fish kills due to manure spills from livestock operations. These external costs can be split as follows: $1133–1162.2 million in damages due to crop production and $11 9 million due to livestock production. Considering the impacts in terms of pesticide use, each kilogram of active ingredient, of 447 million kilograms applied, generates approximately $2.55 in external costs.

Using the above cost totals and 168.8 million hectares of cropland, crop production's injuries to biodiversity cost $6 71–6 89 per hectare annually

The external costs calculated here are substantial and suggest the need for a comprehensive examination of pesticide products and application methods. To curb manure spills, regulations for manure handling at animal feeding operations should continue to be reviewed and enforced and the promotion of other options for livestock finishing should be considered.

(5) Damage to human health: Pathogens

According to the Centers for Disease Control and Prevention (CDC), more than 250 food-transmitted diseases cause an estimated 76 million illnesses, 325,000 hospitalisations and 5200 deaths annually in the United States (CDC, 2002). A Council for Agricultural Science and Technology (CAST) task force estimated microbial foodborne disease cases to number 6.5–33 million annually, with deaths possibly as high as 9000 (CAST, 1994)

Estimates for this category include costs of illnesses associated with foodborne pathogens and costs to the food industry to comply with pathogen reduction regulations. Data are not readily available for other societal costs, such as those incurred by the public health sector or from antibiotic resistance in humans. A recent CAFO air quality study in Iowa describes antibiotic resistance as 'a health threat of great concern' (Iowa State University and The University of Iowa Study Group, 2002: 1–11)

Costs of illnesses associated with waterborne pathogens are not included because states should have implemented the Interim Enhanced Surface Water Treatment Rule (IESWTR) by 1 January 2002. The avoidance benefit of the IESWTR for *Giardia* spp. and *Cryptosporidium parvum* infections due to agriculture is estimated to be between $628 million and $1 billion annually (USEPA, 1997c, 1998a).

(5a) Cost of foodborne illnesses

Most microbial contamination stems from the processing and packaging of animal products According to a USDA web page (2000a), 'Simple changes in food processing and handling practices can eliminate at least 90 percent of foodborne illnesses'. This suggests that 10% of foodborne pathogen contamination arises from production and meal preparation. Zero contamination is not realistic and other entry points for contamination may not be identified, so we estimate that 3% of the health costs in this category are attributable to agricultural production unless otherwise noted

Pathogens causing illness may be bacterial, parasitic, fungal or viral Cost studies by the USDA's Economic Research Service (ERS) have focused on common bacterial agents found in meat, eggs and dairy products. Other food sources include some vegetables, fruits, juices and seafood.

The ERS estimates the annual costs for five bacterial pathogens at $6 9 billion in 2000 dollars (USDA, 2001c). These pathogens are *Campylobacter* spp., *Salmonella*, *E. coli* O157:H7, *E coli* non-O157 STEC, and *Listeria monocytogenes*. In addition to these, Buzby *et al.* (1997) provide damage estimates for the bacteria *Clostridium perfringens* and *Staphylococcus aureus* and the parasite *Toxoplasma gondii* totaling $4.5 billion (1995 dollars). Updating these figures and attributing 3% of the totals to agricultural production, the estimate for the costs of illnesses and deaths from these common pathogens is $375.7 million annually.

This is conservative given that unidentified agents cause the majority of illnesses, and estimates have been calculated only for the common, known pathogens. The CDC (Mead *et al*, 1999) estimates that 82% of foodborne illnesses and 65% of deaths are caused by unknown pathogens. Also, many illnesses go unreported or are not diagnosed as food-related.

Furthermore, these costs include only the impacts on households, in terms of lost productivity and income, medical costs and premature death. Household costs not valued include pain and disability, travel cost for medical care, loss of work time for caregivers and chronic health complications.

(5b) Cost to industry to comply with HACCP rule

In 1997, USDA's Food Safety and Inspection Service (FSIS) issued the first stage of the Pathogen Reduction/Hazard Analysis and Critical Control Point (HACCP) systems rule to meet targets for microbial pathogen reduction. FSIS cites industry costs for meat and poultry plants to comply with HACCP regulations that range from $1.3–2.1 billion in year 2000 dollars (USDA, 2001a). These estimates are based on four scenarios of different pathogen control percentages and interest rates. The estimate for costs due to agricultural production is $40.7–65.8 million, which is 3% of the range of industry costs and updated to 2002 dollars. Costs of complying with HACCP may be considered health costs internalised by the food processing industry, but this 3% is viewed as a cost caused by agricultural production practices, which is externalised beyond the farm gate to processors and consumers.

Category 5 summary

According to this research, damage to human health from foodborne pathogens due to livestock production is calculated at $416.4–441.5 million per year. Although contamination often originates during processing and preparation, livestock health and production methods contribute to a large number of illnesses and should be evaluated to fully address food safety issues. Growing evidence that antibiotic use in livestock increases the resistance of foodborne pathogens reinforces the need to further explore the role of production in this health threat (Iowa State University and The University of Iowa Study Group, 2002)

(6) Damage to human health: Pesticides

Pesticides endanger human health through direct exposure, release into the environment and residues on food. Exposure to pesticides, depending on toxicity and quantity, can cause poisoning, eye damage, respiratory ailments, disruption of the endocrine system (USEPA, 2002c), birth defects, nerve damage, cancer and other effects that may develop over time (USEPA, 2001c). Of particular concern are pesticides that act as endocrine disruptors:

> The endocrine system consists of a set of glands and the hormones they produce that help guide the development, growth, reproduction, and behavior of animals including human beings. ... EPA is concerned about the growing body of evidence that some manmade chemicals may be interfering with normal endocrine system functioning in humans and other animals. (USEPA, 1997d)

Detectable levels of pesticides have been found on approximately 35% of purchased food in the United States (Pimentel *et al.*, 1992). Farm workers who handle and apply pesticides face distinct risks. More than 58,000 unintentional poisonings by agricultural pesticides were reported to the American Association of Poison Control Centers in 2002 (Watson *et al.*, 2003).

(6a) Pesticide poisonings

Very little research has been done to identify and quantify health impacts of pesticides on a national scale for the United States. Studies in the Philippines and Ecuador document health effects and calculate reduction in farmer productivity caused by pesticide use (Antle *et al.*, 1998; Antle & Pingali, 1994; Cole *et al.*, 2000; Crissman *et al*, 1994; Rola & Pingali, 1993). These results, however, are not transferable to agriculture in the United States, considering differences in farmer training and production methods. Here, we rely on Pimentel *et al.* (1992), who calculate the costs of pesticide poisonings and deaths based on hospitalisations, outpatient treatment, loss of work and fatalities due to accidental poisonings and treatment costs for pesticide-induced cancers. Their estimate of $787 million ($1009 million in 2002 dollars) is based, in part, on speculation regarding the incidence of illness and death. However, it could be regarded as conservative considering the number of poisonings reported to control centres. Also, the estimate does not include unreported or misdiagnosed illnesses or costs of chronic ailments, other than cancer, associated with pesticide exposure. In addition, detection techniques are not available for the majority of pesticides used in the United States and their health effects have not been determined (Pimentel *et al.*, 1992).

Part of this valuation may be considered double-counting with the water treatment costs in subsection 1c. However, water treatment processes do not prevent all waterborne exposure and associated illnesses.

Category 6 summary

The cost to human health from pesticides used in crop production is $1009 million annually. Using this valuation and 168.8 million hectares of cropland, human health is affected by pesticide applications on cropland at a level of $5.98 per hectare annually. In terms of pesticide use, the impact to human health translates to $2.26 per kilogram active ingredient. This is a substantial external cost. The damages reported here and in Subsections 1 and 4 call for increased scrutiny of the human and environmental effects of chemical use in agricultural production

In 2002, farmers spent $8 2 billion on pesticides in the United States (USDA, 2004) But, this retail cost reflects less than 80% of the actual cost of pesticide use, when considering the $2253.9–2283.1 million in damages to water resources, wildlife and ecosystem biodiversity and human health calculated here.

Summary

Agricultural production in the United States negatively impacts water, soil, air, wildlife and human health at an estimated cost of $5.7–16.9 billion (£3.3–9.7 billion) per year This is the aggregate cost range from the studies reviewed The breakdown of these costs by production type, as indicated in Table 1, is $4969.3–16,150 5 million per year of impacts due to crop production and $713.6–738.7 million due to livestock production. With the estimate of 168.8 million hectares of cropland in the United States, total external cost per cropland hectare is calculated at $29.44–95.68 (£16.87–54.82), as shown in Table 3 by damage category.

These figures offer a broad, preliminary view of how the externalities of agriculture encumber society And yet, these numbers are conservative, considering we are limited by the complexities of assigning monetary values to environmental and health impacts and the lack of related data.

Comparing our findings with a more comprehensive list of agricultural externalities illustrates the incomplete nature of our national tally. For this we turn to social and natural resource accounting efforts, which attempt to incorporate human and environmental capital assets and flows into traditional income and product measures These assets are not priced in the current market economy and require valuation to be included in social accounts. We refer the reader to other sources for further information on systems of accounts:

- *System of National Accounts* (Commission of the European Communities *et al*, 1993);
- *The Handbook of National Accounting: Integrated Environmental and Economic Accounting* (United Nations *et al*., 2003);
- *A System of Economic Accounts for Food and Agriculture* (Food and Agriculture Organization, 1996);

Table 3 Annual external costs of crop production per hectare

Damage category	*Cost*
Water resources	$1.78
Soil resources	$13.29–79.35
Air resources	$1.68
Biodiversity	$6.71–6.89
Human health – pesticides	$5.98
Totals	**$29.44–95.68 (£16.87–54.82)**

- *Environmental Indicators for Agriculture* (Organisation for Economic Co-operation and Development, 2001).

The environmental indicators listed in Table 4 are a combination of those provided in *Environmental Indicators for Agriculture* and Cabe and Johnson (1990), as well as others we have suggested. Please refer to these sources for further explanation of indicators Also shown in Table 4 are the categories for which we have identified national valuation data.

Clearly, further research is needed on external costs of agriculture, including detailed studies in each impact category, by geographical region and by production type. Comparative valuation studies also would be instructive, i.e. examinations of grazing *vs* feedlot production of livestock or monocropping *vs* diverse cropping systems. In comparing production methods, trade-offs should be taken into account For instance, lower pesticide use often requires increased tillage and possibly causes more soil erosion. Also of interest would be an examination of positive, or beneficial, externalities provided by agriculture, i e carbon sequestration, wildlife habitat and aesthetics Pricing these services may open the door to policy decisions that compensate producers for such 'products'

Conclusion

Many in the United States pride themselves on our 'cheap' food. But, this study demonstrates that consumers pay for food well beyond the grocery store checkout. We pay for food in our utility bills and taxes and in our declining environmental and personal health. These costs total, conservatively, $5.7–16.9 billion (£3.3–9 7 billion) each year. We also support at least $3.7 billion (£2.1 billion) annually in efforts to

Table 4 Agri-environmental indicators

Indicator	*National valuation data for the US*
Nutrient use: balance, efficiency, human health risks	Water treatment for nitrates
Pesticide use and risks	Water treatment Hospitalisations, outpatient treatment, loss of work, fatalities due to accidental poisonings and treatment costs for pesticide-induced cancers
Water use: intensity, efficiency, stress	
Human health risks of production: antibiotic use, waterborne and foodborne pathogens	Water treatment for microbial pathogens Some household costs for illnesses caused by common foodborne pathogens Cost to industry to comply with HACCP rule
Soil erosion by water	For cropland erosion only:
Commercial fisheries	X
Flood damage	X
Industrial users	X
Preservation values	X
Recreation	X
Salinity	
Transportation/navigation	X
Water conveyance	X
Water storage	X
Water treatment	X
Soil erosion by wind	
Human health	
Soiling	
Visibility	
Ground and surface water quality: risks and state	Water treatment for pathogens, nitrates, pesticides
Land conservation	
Water retaining capacity	
Off-farm sediment flow/soil retaining capacity	
Greenhouse gas emissions	X
Biodiversity	
Genetic diversity	
Species diversity: wild, non-native	Impacts to honeybees, beneficial predators, fish, birds
Ecosystem diversity	
Wildlife habitats	
Intensively farmed agricultural habitats	
Semi-natural agricultural habitats	
Uncultivated natural habitats	
Habitat matrix	
Aquatic habitats	
Landscapes	
Structure	
Environmental features, land-use patterns	
Man-made objects/cultural features	
Management	
Costs and benefits	

regulate the present system and mitigate damages. Additional public costs of agricultural production in the United States include direct subsidies and other support mechanisms for farmers. These are not included in our final tally but must be considered in the true cost of food.

What can be done? By using 'ecological' or 'sustainable' methods, some agricultural producers claim to be internalising many of these external costs. However, the market and policy structure in which most producers operate offers narrow return margins and discourages changes in production methods. Considering this, the partial estimate of damage costs presented here promotes responsible, creative policy actions to acknowledge and internalise the externalities of production practices that are generally accepted and widespread.

Furthermore, the estimates presented in this paper are conservative for reasons beyond the need for more valuation data. Many industrial agricultural practices present us with environmental risks that have unknown potential consequences. Potentialities are difficult to define because effects are diffuse in time and location. Some of these risks have been acknowledged scientifically but not necessarily politically, i.e. ecosystem behaviour in a monocropped environment, antibiotic resistance in humans, loss of pollinators.

Political intention is required to reassess and reform agricultural policy. Programmes that highlight sustainable methods rather than destructive, risky practices would be a start in internalising the true costs of the present system.

References

Adger, W.N. and Whitby, M.C. (1991) National accounts and environmental degradation: Accounting for the impact of agriculture and forestry on environmental quality. *European Economic Review* 35, 629–641.

Adger, W.N. and Whitby, M.C. (1993) Natural-resource accounting in the land-use sector: Theory and practice. *European Review of Agricultural Economics* 20, 77–97.

Altieri, M. (1995) *Agroecology: The Science of Sustainable Agriculture*. Boulder, Colorado: Westview Press.

American Bird Conservancy (2002) News release: Conservation groups prevent use of eagle-killing pesticide. July 29. On WWW at http://www.abcbirds.org/media/releases/carbofuran_victory_release.htm [December 20, 2003].

American Fisheries Society (1982) *Monetary Values of Freshwater Fish and Fish-kill Counting Guidelines*. Special publication No. 13. Bethesda, Maryland: American Fisheries Society.

Antle, J.M., Cole, D.C. and Crissman, C.C. (1998) Further evidence on pesticides, productivity and farmer health: Potato production in Ecuador. *Agricultural Economics* 18, 199–207.

Antle, J.M. and Pingali, P. (1994) Pesticides, productivity, and farmer health: A Philippine case study. *American Journal of Agricultural Economics* 76, 418–430.

Atwood, J. (1994) *RCA Reservoir Sediment Data Reports 1–5*. Washington DC: Soil Conservation Service.

Baumol, W.J. and Oates, W.E. (1988) *The Theory of Environmental Policy*. Cambridge: Cambridge University Press.

Bejranonda, S., Hitzhusen, F.J. and Hite, D. (1999) Agricultural sedimentation impacts on lakeside property values. *Agricultural and Resource Economics Review* 28 (2), 208–218.

Bollman, R.A. and Bryden, J.M. (eds) (1997) *Rural Employment: An International Perspective*. Wallingford: CAB International.

Bonnieux, F., Rainelli, P. and Vermersch, D. (1998) Estimating the supply of environmental benefits by agriculture: A French case study. *Environmental and Resource Economics* 11, 135–153.

Brouwer, R. (1999) *Market Integration of Agricultural Externalities: A Rapid Assessment Across EU Countries*. Copenhagen: European Environment Agency.

Buzby, J.C., Roberts, T. and Allos, B.M. (1997) Estimated annual costs of *Campylobacter*-associated Guillain-Barré Syndrome. Agricultural Economic Report No. 756. Washington DC: USDA, Economic Research Service.

Cabe, R. and Johnson, S.R. (1990) Natural resource accounting systems and environmental policy modeling. *Journal of Soil and Water Conservation*, 533–539.

Cavigelli, M.A., Deming, S.R., Probyn, L.K. and Harwood, R.R. (eds) (1998) *Michigan Field Crop Ecology: Managing Biological Processes for Productivity and Environmental Quality*. Extension Bulletin E-2646. East Lansing, Michigan: Michigan State University.

Centers for Disease Control and Prevention (1996) *Surveillance for Waterborne-Disease Outbreaks – United States, 1993–1994*. 45(SS-1). Atlanta, Georgia: Centers for Disease Control and Prevention. On WWW at http://www.cdc.gov/epo/mmwr/preview/mmwrhtml/00040818.htm [December 20, 2003].

Centers for Disease Control and Prevention (2002) Disease information – Foodborne infections. On WWW at http://www.cdc.gov/ncidod/dbmd/diseaseinfo/foodborneinfections_t.htm [December 20, 2003].

Chicago Climate Exchange (2004) On WWW at http://www.chicagoclimatex.com/ [February 10, 2004].

Clark, E.H. II, Haverkamp, J.A. and Chapman, W. (1985) *Eroding Soils: The Off-farm Impacts*. Washington DC: The Conservation Foundation.

Clean Water Network, the Izaak Walton League of America, and the Natural Resources Defense Council (2000) *Spills and Kills: Manure Pollution and America's Livestock Feedlots*. Washington DC: Clean Water Network. On WWW at http://www.cwn.org [December 20, 2003].

Colacicco, D., Osborn, I and Alt, K (1989) Economic damage from soil erosion *Journal of Soil and Water Conservation* 44, 35–39

Cole, D.C , Carpio, F. and León, N (2000) Economic burden of illness from pesticide poisonings in highland Ecuador *Pan American Journal of Public Health* 8 (3), 196–201

Commission of the European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank (1993) *System of National Accounts*. On WWW at http://unstats un.org/unsd/sna1993/introduction asp [April 29, 2004].

Conway, G R and Pretty, J.N. (1991) *Unwelcome Harvest: Agriculture and Pollution* London: Earthscan.

Council for Agricultural Science and Technology (1994) *Foodborne Pathogens: Risks and Consequences*. Task Force Report No 122. Washington DC: Council for Agricultural Science and Technology.

Crissman, C.C., Cole, D.C. and Carpio, F (1994) Pesticide use and farm worker health in Ecuadorian potato production. *American Journal of Agricultural Economics* 76, 593–597.

Crosson, P. (1986) In I. Phipps, P Crosson and K. Price (eds) *Agriculture and the Environment* (pp. 35–73) Washington DC: Resources for the Future.

Crowder, B.M (1987) Economic costs of reservoir sedimentation: A regional approach to estimating cropland erosion damage. *Journal of Soil and Water Conservation* 42 (3), 194–197.

Crutchfield, S.R , Cooper, J.C and Hellerstein, D. (1997) *Benefits of Safer Drinking Water: The Value of Nitrate Reduction*. Agricultural Economic Report No 752. Washington DC: USDA, Economic Research Service

Evans, R (1996) *Soil Erosion and Its Impact in England and Wales* London: Friends of the Earth Trust

Faeth, P. and Repetto, R (1991) *Paying the Farm Bill: U.S Agricultural Policy and the Transition to Sustainable Agriculture*. Washington DC: World Resources Institute.

Farber, S.C , Costanza, R and Wilson, M.A (2002) Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41, 375–392.

Federal Emergency Management Agency (2002) Resources for parents & teachers. On WWW at http://www fema.gov/kids/98wdgen.htm [December 20, 2003]

Flora, J.L , Hodne, C.J., Goudy, W , Osterberg, D., Kliebenstein, J., Thu, K.M. and Marquez, S.P. (2002) Social and community impacts In Iowa State University and The University of Iowa Study Group, *Iowa Concentrated Animal Feeding Operations Air Quality Study* Iowa City, Iowa: Environmental Health Sciences Research Center. On WWW at http://www.public-health.uiowa edu/ehsrc/CAFO study.htm [December 20, 2003]

Food and Agriculture Organization of the United Nations (1996) *A System of Economic Accounts for food and Agriculture*. On WWW at http://www.fao.org/docrep/W0010E/W0010E00 htm [April 29, 2004]

Food and Drug Administration (2002) Budget information. On WWW at http://www.fda gov/oc/oms/of/budget/2002/CJ2002/HTML/CFSAN.htm [December 20, 2003].

Freeman, A.M , III (1982) *Air and Water Pollution Control: A Benefit-Cost Assessment*. New York: John Wiley and Sons

Freeman, A.M , III (1998) On valuing the services and functions of ecosystems In A.M. Freeman (ed.) *The Economic Approach to Environmental Policy: The Selected Essays of A Myrick Freeman III.* Cheltenham, UK and Northampton, MA: Edward Elgar

Gianessi, L.P and Marcelli, M.B. (2000) *Pesticide Use in U.S. Crop Production: 1997* Washington DC: National Center for Food and Agricultural Policy. On WWW at http://www ncfap.org/ncfap/national summary1997.pdf [December 20, 2003].

Graf, W.L. (1993) Landscapes, commodities, and ecosystems: The relationship between policy and science for American rivers. In *Sustaining our Water Resources*. Washington DC: National Academy Press.

Hanley, N., Shogren, J F. and White, B. (1997) *Environmental Economics in Theory and Practice*. New York and Oxford: Oxford University Press.

Hartridge, O and Pearce, D W. (2001) *Is UK Agriculture Sustainable? Environmentally Adjusted Economic Accounts for UK Agriculture* London: CSERGE-Economics, University College London.

Holmes, T (1988) The offsite impact of soil erosion on the water treatment industry. *Land Economics* 64 (4), 356–366.

Hrubovcak, J , LeBlanc, M and Eakin, B K. (2000) Agriculture, natural resources and environmental accounting. *Environmental and Resource Economics* 17, 145–162.

Iowa State University and The University of Iowa Study Group (2002) *Iowa Concentrated Animal Feeding Operations Air Quality Study* Iowa City, Iowa: Environmental Health Sciences Research Center. On WWW at http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm [December 20, 2003]

Juranek, D. (1995) *Cryptosporidiosis*: Source of infection and guidelines for prevention *Clinical Infectious Diseases* 21, 57–61.

Lawrence, G.B., Goolsby, D.A. and Battaglin, W.A. (1999) *Atmospheric Deposition of Nitrogen in the Mississippi River Basin*. Proceedings of the U S Geological Survey Toxic Substances Hydrology Program technical meeting, Charleston, South Carolina, March 8–12 On WWW at http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionC/2413_Lawrence/index.html [December 2, 2003].

le Goffe, P. (2000) Hedonic pricing of agriculture and forestry externalities. *Environmental and Resource Economics* 15, 397–401.

Mead, P.S , Slutsker, L., Dietz, V., McCaig, L.F., Bresee, J.S , Shapiro, C , Griffin, P.M. and Tauxe, R.V (1999) *Food-related Illness and Death in the United States-Synopses* Atlanta, Georgia: Centers for Disease Control and Prevention. On WWW at http://www.cdc.gov/ncidod/eid/vol5no5/mead.htm#Figure%201 [December 20, 2003].

Mineau, P , Baril, A., Collins, B T., Duffe, J , Joerman, G. and Luttik, R (2001) Pesticide acute toxicity reference values for birds. *Reviews of Environmental Contamination and Toxicology* 170, 13–74

Miranowski, J.A and Carlson, G.A (1993) Agriculture resource economics: An overview. In G.A Carlson, D. Zilberman and J.A. Miranowski (eds) *Agricultural and Environmental Resource Economics* Oxford: Oxford University Press.

Morris, G L and Fan, J. (1998) *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Uses*. New York: McGraw-Hill

Morse, R.A. and Calderone, N.W. (2000) The value of honey bees as pollinators of U.S. crops in 2000. On WWW at http://bee.airoot.com/beeculture/pollination2000/pg1.html [December 20, 2003].

National Coalition Against the Misuse of Pesticides (2002) News release: EPA allows use of banned insecticide, deadly to birds, on 10,000 acres, will decide whether to allow the program to go forward this week July 3. On WWW at http://www.beyondpesticides.org/WATCHDOG/media/carbofuran_07_03_02.htm [December 20, 2003]

National Research Council, Board on Agriculture, Committee on the Role of Alternative Farming Methods in Modern Production Agriculture. (1989) *Alternative Agriculture*. Washington DC: National Academy Press.

Organisation for Economic Co-operation and Development (2001) *Environmental Indicators for Agriculture*. On WWW at http://www.oecd.org/dataoecd/0/9/1916629.pdf [April 29, 2004]

Pell, A.N (1997) Manure and microbes: Public and animal health problem? *Journal of Dairy Science* 80, 2673–2681

Pesticide Management Education Program at Cornell University (1991) News release: Carbofuran phased out under settlement agreement 5/91 May 14. On WWW at URL http://pmep.cce.cornell.edu/profiles/insect-mite/cadusafos-cyromazine/carbofuran/gran-carbo-dec.html [December 20, 2003]

Pimentel, D , Acquay, H., Biltonen, M , Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A. and D'Arnor, M (1992) Environmental and economic costs of pesticide use. *BioScience* 42 (10), 750–760.

Pimentel, D., Harvey, C., Resosudarmo, P , Sinclair, K , Kurz, D , McNair, M., Crist, S., Shpritz, L , Fitton, L , Saffouri, R and Blair, R. (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1123

Piot-Lepetit, I., Vermersch, D. and Weaver, R D. (1997) Agriculture's environmental externalities: DEA evidence for French agriculture. *Applied Economics* 29 (3), 331–338

Pretty, J N., Brett, C., Gee, D , Hine, R.E., Mason, C F., Morison, J.I.L., Raven, H , Rayment, M D and van der Bijl, G. (2000) An assessment of the total external costs of UK agriculture *Agricultural Systems* 65, 113–136.

Pretty, J.N., Mason, C.F., Nedwell, D.B., Hine, R E., Leaf, S. and Dils, R. (2003) Environmental costs of freshwater eutrophication in England and Wales. *Environmental Science & Technology* 37 (2), 201–208.

Ribaudo, M O. (1989) *Water Quality Benefits from the Conservation Reserve Program*. Agricultural Economic Report No. 606 Washington DC: USDA, Economic Research Service.

Rola, A. and Pingali, P (1993) *Pesticides, Rice Productivity, and Farmers' Health: An Economic Assessment*. Manila: International Rice Research Institute

Samuelson, P A and Nordhaus, W D. (1995) *Economics*. New York: McGraw-Hill.

Schou, J S (1996) Indirect regulation of externalities: The case of Danish agriculture *European Environment* 6 (5), 162–167.

Smith, V.K. (1992) Environmental costing for agriculture: Will it be standard fare in the Farm Bill of 2000? *American Journal of Agricultural Economics* 74 (5), 1076–1088.

Southwick, E E. and Southwick, L., Jr. (1992) Estimating the economic value of honeybees (*Hymenoptera Apidae*) as agricultural pollinators in the United States. *Economic Entomology* 85 (3), 621–633

Steiner, R.A., McLaughlin, L , Faeth, P. and Janke, R.R (1995) Incorporating externality costs into productivity measures: A case study using U.S. agriculture. In V Barnett, R. Payne and R. Steiner (eds) *Agricultural Sustainability: Economic, Environmental and Statistical Considerations* New York: John Wiley & Sons.

Thorne, P.S. (2002) Air quality issues In Iowa State University and The University of Iowa Study Group *Iowa Concentrated Animal Feeding Operations Air Quality Study* Iowa City, Iowa: Environmental Health Sciences Research Center. On WWW at http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm [December 20, 2003]

Tiezzi, S (1999) External effects of agricultural production in Italy and environmental accounting *Environmental and Resource Economics* 13, 459–472.

Titus, J G (1992) The costs of climate change to the United States. In S.K. Majumdar, L.S. Kalkstein, B. Yarnal, E.W. Miller and L.M Rosenfeld (eds) *Global Climate Change: Implications, Challenges, and Mitigation Measures* East Stroudsburg, Pennsylvania: Pennsylvania Academy of Sciences. On WWW at http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsSLR_US_Costs.html [December 2, 2003].

United Nations, European Commission, International Monetary Fund, Organisation for Economic Cooperation and Development and World Bank (2003) *Handbook of National Accounting: Integrated Environmental and Economic Accounting*. On WWW at http://unstats.un.org/unsd/environment/seea2003.htm [April 29, 2004]

US Army Corp of Engineers, Navigation Data Center, Dredging Program (2003) FY2002 analysis of dredging costs. On WWW at http://www.iwr.usace.army.mil/ndc/dredge/dredge.htm [December 20, 2003].

US Department of Agriculture, Animal and Plant Health Inspection Service (1994) *Cryptosporidium and Giardia in Beef Calves*. National Animal Health-Monitoring System report Washington DC: USDA

US Department of Agriculture, Natural Resources Conservation Service (1995) *RCA III, Sedimentation in Irrigation Water Bodies, Reservoirs, Canals, and Ditches* Working Paper No 5 Washington DC: USDA. On WWW at http://www.nrcs usda gov/technical/land/pubs/wp05text.html [December 20, 2003]

US Department of Agriculture (2000a) Cleaning up our act: Food safety is everybody's business. On WWW at http://www reeusda gov/success/impact00/safefood htm [December 20, 2003]

US Department of Agriculture, Economic Research Service (2000b) Land use. In Economic Research Service, *Agricultural Resources and Environmental Indicators*. Washington DC: USDA.

US Department of Agriculture, Natural Resources Conservation Service (2000c) *National Resources Inventory, 1997*. Washington DC: USDA. On WWW at http://www.nrcs.usda.gov/technical/land/meta/m5112.html [December 20, 2003].

US Department of Agriculture, Economic Research Service (2000d) Water quality impacts of agriculture *In Agricultural Resources and Environmental Indicators*. Washington DC: USDA.

US Department of Agriculture, Natural Resources Conservation Service (2000e) *Waterborne Pathogen Information Sheet – Principal Pathogens of Concern, Cryptosporidium and Giardia* Washington DC: USDA. On WWW at http://wvlc.uwaterloo.ca/biology447/modules/module8/SludgeDisposal/Pathogen_information_Sheet-Cryptosporidium_and_Giardia.pdf [December 20, 2003].

US Department of Agriculture, Economic Research Service (2001a) Briefing room – Government food safety policies: features. On WWW at http://www ers usda gov/briefing/FoodSafetyPolicy/features.htm [December 20, 2003].

US Department of Agriculture, Natural Resources Conservation Service (2001b) National resources inventory highlights On WWW at http://www nrcs.usda gov/technical/land/pubs/97highlights.pdf [December 20, 2003]

US Department of Agriculture, Economic Research Service (2001c) Research emphasis – Food safety: features. On WWW at http://www ers.usda.gov/Emphases/SafeFood/features htm [December 20, 2003]

US Department of Agriculture (2002a) Action plan. On WWW at http://www nps.ars usda gov [December 20, 2003].

US Department of Agriculture (2002b) FY2003 budget summary. On WWW at http://www.usda gov/agency/obpa/Budget-Summary/2003 [December 20, 2003]

US Department of Agriculture, Economic Research Service (2004) Farm income data. On WWW at http://www ers usda.gov/Data/FarmIncome/finfidmu htm [February 12, 2004].

US Environmental Protection Agency (1997a) *Drinking Water Infrastructure Needs Survey: First Report to Congress* EPA 812-R-97-001. Washington DC: USEPA

US Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds (1997b) *Managing Nonpoint Source Pollution from Agriculture*. Pointer No 6. EPA841-F-96-004F. Washington DC: USEPA. On WWW at http://www.epa.gov/OWOW/NPS/facts/point6 htm [December 20, 2003].

US Environmental Protection Agency (1997c) National primary drinking water regulations: Interim enhanced surface water treatment rule notice of data availability-proposed rule. *Federal Register* November 3, 59486–59557 Washington DC: Office of the Federal Register, National Archives and Records Administration

US Environmental Protection Agency (1997d) Potential of chemicals to affect the endocrine system. On WWW at http://www epa.gov/pesticides/factsheets/3file htm [December 20, 2003]

US Environmental Protection Agency, Office of Water (1998a) *Interim Enhanced Surface Water Treatment Rule*. EPA 815-F-99-009. Washington DC: USEPA. On WWW at http://www.epa.gov/safewater/mdbp/ieswtr.html [December 20, 2003].

US Environmental Protection Agency, Office of Water (1998b) *Small System Compliance Technology List for the Non-microbial Contaminants Regulated before 1996*. EPA 815-R-98-002. Washington DC: USEPA. On WWW at http://www epa gov/safewater/standard/tlstnm.pdf [December 20, 2003].

US Environmental Protection Agency, Biological and Economic Analysis Division, Office of Pesticide Programs (1999a) *Pesticide Industry Sales and Usage: 1996 and 1997 Market Estimates Report*. 733-R-99-001. Washington DC: USEPA. On WWW at http://www epa.gov/oppbead1/pestsales/ [December 20, 2003].

US Environmental Protection Agency, Office of Atmospheric Programs (1999b) *Regulatory Impact Analysis for the Final Section 126 Petition Rule*. Washington DC: USEPA. On WWW at http://www.epa.gov/ttn/ecas/regdata/126fn0 pdf [December 20, 2003].

US Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds (2001a) *Nonpoint Source Pollution: The Nation's Largest Water Quality Problem*. Pointer No 1. EPA841-F-96-004A Washington DC: USEPA. On WWW at http://www.epa.gov/OWOW/NPS/facts/point1.htm [December 20, 2003]

US Environmental Protection Agency (2001b) Pesticides and food: Health problems pesticides may pose. On WWW at http://www.epa.gov/pesticides/food/risks.htm [December 20, 2003].

US Environmental Protection Agency, Office of Water (2001c) Where does my drinking water come from? On WWW at http://www epa.gov/OGWDW/wot/wheredoes html [December 20, 2003]

US Environmental Protection Agency (2002a) Food Quality Protection Act (FQPA) background. On WWW at http://www.epa.gov/opppsps1/fqpa/backgrnd.htm [December 20, 2003]

US Environmental Protection Agency, Clean Air Market Programs (2002b) *Nitrogen: Multiple and Regional Impacts* EPA-430-R-01-006. Washington DC: USEPA. On WWW at http://www.epa.gov/airmarkets/articles/nitrogen pdf [December 2, 2003].

US Environmental Protection Agency (2002c) Pesticide effects. On WWW at http://www epa.gov/ebtpages/pestpesticideeffects.html [December 20, 2003].

US Environmental Protection Agency (2002d) Summary of the EPA's budget, FY2003. On WWW at http://www.epa.gov/ocfo/budget/2003/2003bib.pdf [December 20, 2003]

US Environmental Protection Agency (2003) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2001*. EPA 430-R-03-004. Washington DC: USEPA. On WWW at http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html [December 2, 2003]

US Geological Survey (1998) *Estimated Use of Water in the United States in 1995*. Circular 1200. Washington DC: Government Printing Office. On WWW at http://water.usgs.gov/watuse/pdf1995/html/ [December 20, 2003].

Vaughan, W.J. and Russell, C.S. (1982) *Freshwater Recreational Fishing – The National Benefits of Water Pollution Control*. Prepared for Resources for the Future. Baltimore, Maryland: Johns Hopkins University Press.

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E. (1997) Human alternation of the global nitrogen cycle – sources and consequences. *Ecological Applications* 7, 737–750.

Waibel, H. and Fleischer, G. (1998) *Kosten und Nutzen des chemischen Pflanzenschutzes in der deutschen Landwirtschaft aus gesamtwirtschaftlicher Sicht* (Social Costs and Benefits of Chemical Pesticide Use in German Agriculture). Kiel: Wissenschaftsverlag Vauk. On WWW at http://www.ifgb.uni-hannover.de/ppp/publications.htm [December 3, 2003]

Watson, W.A., Litovitz, T.L., Rodgers, G.C., Klein-Schwartz, W., Youniss, J., Rutherfoord-Rose, S., Borys, D. and May, M.E. (2003) 2002 Annual Report of the American Association of Poison Control Centers Toxic Exposure Surveillance System. *The American Journal of Emergency Medicine* 21(5), 353–421. On WWW at http://www.aapcc.org [December 2, 2003]

Zilberman, D. and Marra, M. (1993) Agricultural externalities. In G.A. Carlson, D. Zilberman and J.A. Miranowski (eds) *Agricultural and Environmental Resource Economics*. Oxford: Oxford University Press.